THE GREAT UNKNOWN

Fifty years ago it was evident that X-rays were useful for seeing through objects, such as the human body, which are opaque to ordinary light. It could not be predicted that X-rays would become a powerful weapon in the fight against cancer, or that the study of X-rays would lead to the discovery of radioactivity and stimulate the development of radio, radar, and a host of electronic devices. Such unforseen developments are the result of every great discovery. It would, therefore, be surprising if the most important consequences of the release of atomic energy are not in directions as yet unpredictable.

The Story of

ATOMIC ENERGY

WITH
SAFE, INTERESTING EXPERIMENTS

Exclusive with CHEMCRAFT

$_{93}Np^{239}$

$E = mc^2$

$_{88}^{226}$

$_{94}Pu^{239}$

GAMMA

A SAFE, THRILLING INTRODUCTION
TO THE MYSTERIES AND MIRACLES
OF AN ATOMIC WORLD

HARMLESS! EXCITING! PRACTICAL!

THE PORTER CHEMICAL CO., HAGERSTOWN, MD.

FOREWORD

The authentic information on atomic energy presented in this book has been gathered from a large number of reliable sources. Included among these sources are the works of noted physicists and chemists and the latest reports released by the United States Atomic Energy Commission.

At the time of going to press there is not, to our knowledge, any other popular book covering the subject of atomic energy as complete as herein set forth.

THE STORY OF ATOMIC ENERGY WITH SAFE EXPERIMENTS

by
Harold M. Porter
and
Jermain D. Porter, PhD.

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The Porter Chemical Company
Hagerstown, Maryland

INTRODUCTION

Every new discovery in science adds new revelations and new problems to our already complicated civilization. People of more advanced years often look back to the days of their youth when life was much more simple and responsibilities fewer. We can not ignore scientific progress, however, and it is the duty of all of us to welcome new discoveries in a spirit of progressiveness and to equip ourselves mentally to do our part in guiding these new discoveries into constructive instead of destructive applications.

Thus it is with atomic energy. Guided into channels of usefulness, atomic energy will become as great a servant to mankind as fire. Allowed to follow destructive channels, atomic energy could conceivably destroy our world. Controlled it can become the most beneficial force ever discovered by man.

The basis of civilization is knowledge. Therefore, let us learn about atomic energy and each be prepared to do his part in making this great discovery benefit all mankind. It is with this thought that we present this elementary booklet describing atomic energy to you — the youth of America.

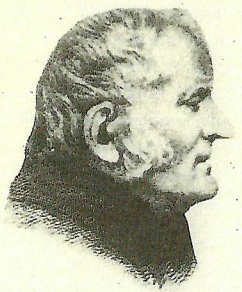
We have endeavored to make the explanation of atomic energy relatively simple and easily understandable, and for this reason, we have not gone into the many complicated theories and conplex mathematical equations which are involved in a more thorough presentation of the subject. We have presented experiments that you can perform yourself, and which will illustrate many of the interesting theories described in the booklet. With this elementary knowledge of atomic energy, you will be in position to understand future developments and to do your part as time goes on to help atomic energy make our world a better place in which to live.

H. M. P.

CHAPTER I

HISTORY OF ATOMIC ENERGY

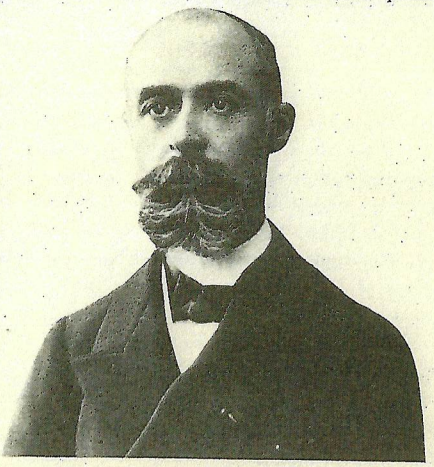
For more than a century, since John Dalton proposed his atomic theory, scientists have known that all matter is composed of atoms, but it is only much more recently that we have even suspected what a tremendous store of energy lies locked within each atom. And only within the past few years have we learned how a portion of this energy can be released from certain atoms.



John Dalton

Let us go back half a century, to 1896. X-rays had just been discovered, and scientists were busily looking for other examples of invisible rays. Henri Becquerel in Paris had been experimenting with a compound containing uranium and one day happened to place some of it in a drawer with some photographic plates. The plates, to his amazement, became fogged, even though they had been wrapped in black paper. Further experiments showed that the uranium compound was giving out invisible but penetrating rays, rays which passed through black paper and even through thin sheets of metal.

Pierre and Marie Curie, also working in Paris, at once began to investigate this remarkable phenomenon. They soon discovered that pitchblend, an ore of uranium emitted stronger radiation than uranium itself. After six years of the most difficult and discouraging labor, they obtained, starting from tons of pitchblende, a tiny quantity of the first pure salt of radium, a hitherto unknown metal, which sends out rays a million times as intense as those from uranium.



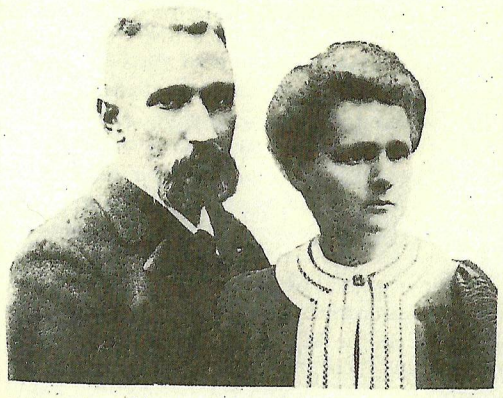
Henri Becquerel

Within a few years is had been established that radioactivity, this peculiar property possessed by uranium, radium, and a few other substances is due to an actual breaking down, or disintregration, of their atoms.

The study of radioactivity was one of the chief sources of our present view of the atom as being composed of a nucleus, containing positively charged protons, surrounded by negative electrons.

In 1919, Lord Rutherford, using rays from a radioactive substance, changed artificially for the first time one kind of atom into another, on, however, an extremely small scale.

Another important step based upon the use of radioactivity as a research tool was taken in 1932, when Chadwick in England discovered the neutron, a particle without electrical charge. Neutrons are now known to be present along with protons in the nuclei of atoms. They play a very important part in the release of atomic energy.



Pierre and Marie Curie

With the development of the cyclotron and similar "atom-smashing" devices around 1932, it became possible to bombard atoms with a greater variety of particles having very high energies. The research worker was no longer dependent upon expensive radioactive materials for his high-speed particles, but could produce them at will in great abundance.

With these new resources it was very quickly proved that the famous Einstein mass-energy equation was correct. This equation, based upon the Einstein theory of relativity, tells us how much energy is obtained when a given weight of matter is converted into energy.

At about the same time, Fermi in Rome was systematically studying the effect of neutrons upon each of the chemical elements. When he reached the heaviest kind of atom then known, that of uranium, he obtained some curious results. These were not correctly explained until 1939, when Hahn and Strassmann proved that bombardment of uranium by neutrons causes the uranium atoms to split apart into two more or less equal fragments. This was an entirely new finding, totally different from ordinary radioactivity. As we shall see later, this splitting, or atomic fission, is accompanied by the release of a tremendous amount of energy. It is the key process in the production of atomic energy.

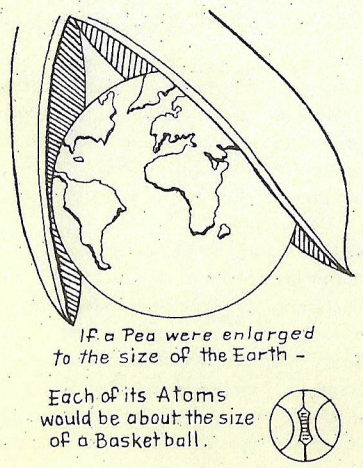
Between 1939 and the first explosion of an atomic bomb in 1945, there was feverish activity among the atomic scientists, most of it under the cloud of war censorship. It was found that only one rather rare kind of uranium atom (U-235) is subject to fission and that when it splits, several neutrons are released, which may then cause fission of another atom, and so on. Thus the possibility of a self-sustaining chain reaction was recognized. Further, the entirely new element, plutonium, was made by the action of neutrons upon ordinary uranium atoms (U-238) and was shown to undergo fission itself.

Finally, a large number of very formidable scientific and engineering problems were overcome during the war years to bring into practical application the laboratory experiments and the theoretical results we have just sketched. The climax was the atomic bomb, but that was not the end, for with the coming of peace, the atomic scientists have applied their talents to the problem of constructive uses for atomic energy, and the history of a new era is just beginning to be written in their laboratories.

CHAPTER II
STRUCTURE OF THE ATOM

All substances — elements, compounds, and mixtures — are composed of atoms. Thus atoms are the building blocks of all matter, whether in the solid, liquid, or gaseous state, including air, water, rocks, metals, everything we eat, drink, and wear, and even our own bodies.

It used to be thought that atoms were hard little balls quite impossible to split up into smaller pieces. We know now, however, that atoms, tiny though they are, are themselves built up of still smaller units. In this chapter we are going to learn something about these units and how they are combined into atoms. It is only by understanding the structure of atoms that we can tap the tremendous supplies of energy within them.

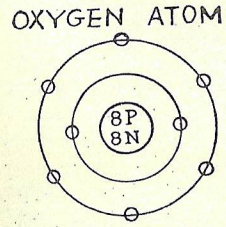


Even the largest of the atoms is so inconceivably small that it would mean little to say that it measures only a few billionths of an inch across. Perhaps it may help to put it another way and state that there are 30 billion times more atoms in the head of a pin than there are people on the earth.

Or, from still another point of view, suppose we imagine a pea enlarged until it is the size of the earth. Then each of the atoms which make it up, enlarged in the same proportion, would still be no larger than a basketball.

From the point of view of chemical behavior nearly a hundred different kinds of atoms are now known, corresponding to the ninety some known elements. If we consider, however, atoms which differ merely in weight but not in chemical nature, the number of different kinds amounts to several hundred. Two atoms of the same chemical element which differ from each other only in weight are said to be *isotopes* of that element. For example, tin has ten stable isotopes, for there are ten different kinds of tin atoms all mixed together in a piece of ordinary tin. They all behave chemically like tin atoms, but differ among themselves in weight.

Because of their extremely small size, atoms cannot be seen even with the most powerful microscope. Nevertheless, from experiments which tell us about their behavior, chemists and physicists have been able to deduce many things about their structure. We know with certainty that nearly all of the mass, or weight, of an atom, more than 99.9% of it at least, is concentrated at its very center, in a very small fraction of the atom's volume. We call this heavy little core the *nucleus*. Locked within it is the greater part of the atom's store of energy.



Moving about the nucleus at fairly definite distances are tiny particles bearing charges of negative electricity. These are called *electrons*. Compared with the size of the nucleus and of the electrons, the distances between them are very large, and we must imagine the atom as being composed mostly of absolutely empty space.

If we could magnify a tiny atom to the size of a great football stadium, the nucleus might be represented by a golf-ball lying on the 50-yard line, while the electrons would be like a swarm of mosquitos buzzing around the outer row of seats. Or the atom may be compared with our solar system, in which the planets, among them our earth, revolve at enormous distances about the sun.

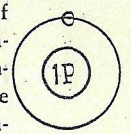
Since the electrons all have charges of negative electricity, they repel each other. It is the repulsion between the electrons of neighboring atoms which makes it impossible for two objects to occupy the same space at the same time.

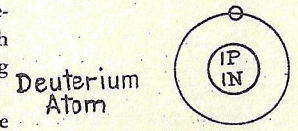
For an understanding of atomic energy, the nucleus is more important than the electrons. The nucleus of atoms is composed of two kinds of particles, *protons* and *neutrons*. Protons are positively charged particles, about 1840 times as heavy as electrons. Neutrons are particles of about the same weight as protons, but they have no electrical charge.

The number of protons in the nucleus of an atom is the *atomic number* of that atom. Since protons and electrons have equal, though opposite, electrical charges, there must be as many electrons around the nucleus of a normal neutral atom as there are protons in the nucleus. Then the negative electrons will exactly counterbalance the positive charge of the protons, and the atom as a whole will be neutral.

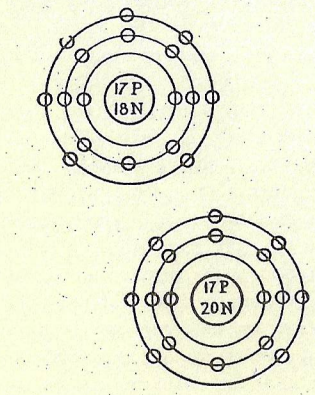
The total number of particles in the nucleus — protons and neutrons together — is called the *mass number* of the atom. It corresponds closely to the atomic weight used by the chemist. Since the protons and neutrons are equal in weight, while the electrons are negligible in comparison, the mass numbers of the atoms tell us their relative weights, just as the atomic numbers tell us the number of units of positive charge on their nuclei.

All the isotopes of the same element have the same atomic number, but differ in mass number, that is, in atomic weight. This is the same as saying that they have the same number of protons in their nuclei, but different numbers of neutrons. If the number of protons is the same for two or more isotopes, then the number of electrons will also be the same. Now in chemical reactions, only the outer electrons are concerned, so that two atoms with the same number of electrons will show identical chemical behavior, and the chemist will say they belong to the same element. This agrees with what we said above about isotopes being identical chemically.





Perhaps some of these things will be made clearer by a few examples. Consider first the simplest of all atoms, that of ordinary hydrogen. Its atomic number and its mass number are both one (1), so its nucleus consists of a single proton, and of course, there is a single electron revolving around the nucleus. Hydrogen has an isotope, the so-called heavy hydrogen, or deuterium. Its atomic number is naturally, also one, but its mass number is two, showing its nucleus to contain besides a proton, also one neutron. Thus the only difference between these two isotopes of hydrogen is that the heavier one has a neutron in its nucleus.



Ordinary chlorine gas is a mixture of two isotopes, both having the atomic number 17, meaning 17 protons in the nucleus. One has a mass number of 35, showing that its nucleus has 18 neutrons in

addition to the 17 protons (to make a total of 35 particles). The mass number of the other is 37, and its nucleus therefore is made up of 20 neutrons plus 17 protons.

The "average mass number" of the isotopes in ordinary chlorine is 35.46, and is what the chemist called the atomic weight of chlorine. It is closer to 35 than to 37 because the isotope of mass number 35 is present in greater amount.

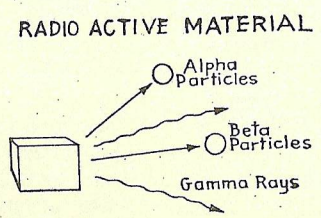
In the next chapter we are going to see that an understanding of isotopes is essential in obtaining a clear conception of radioactivity.

CHAPTER III
RADIOACTIVE ATOMS

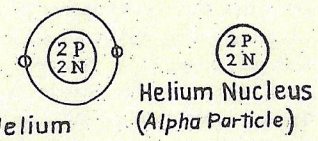
In the nucleus of an ordinary atom the protons and neutrons appear to be cemented together into a balanced and stable structure. Atoms of a few of the less common elements, however, have nuclei which are so unstable that they break down spontaneously with a sort of nuclear explosion. Such atoms are said to be radioactive, and as pointed out in Chapter I, the study of radioactivity was one of the important steps toward the mastery of atomic energy.

A sample of a radioactive element steadily gives off energy in the form of radiation and in doing so changes into other elements. Nothing we can do has the slightest effect upon the rate at which this change proceeds. We can chill it below the temperature of liquid air or bake it at white heat of the electric furnace, but the disintegration of the atoms and the emission of energy go right on at exactly the same speed. We can join the atoms into chemical compounds or put them under tremendous pressure, still without the slightest effect upon their decomposition.

Evidently we are dealing here with something much different from the usual chemical reactions which atoms undergo. The carbon of coal, for example, combines rapidly with oxygen (burns) at a red heat, but at room temperature the combination does not take place at all. In a chemical reaction such as the burning of carbon, atoms of two different elements (carbon and oxygen) combine to form molecules of a compound (carbon dioxide) with the release of



energy in the form of heat. Radioactivity, on the other hand, is an actual decomposition of single atoms. A radioactive atom shoots out a ray of some sort and thereafter is an atom of an entirely different element. The total energy released is thousands of times greater than that from the combustion of an equal weight of coal.



Three types of rays are emitted by radioactive substances. They are called alpha, beta, and gamma rays.

Alpha rays are streams of rapidly moving particles which are the same in mass and charge as the nuclei of helium atoms. That is, they have a mass number of 4 and bear two units of positive charge. The two positive charges show that the alpha particle contains two protons, and mass number indicates the presence in them of two neutrons in addition. Alpha particles, although they are shot out with speeds of around 10,000 miles per second, travel only a short distance before being stopped by collisions with atoms in their path. They are stopped by even a thin sheet of paper or metal foil, but in air they may travel as far as an inch or two.

Beta rays are streams of electrons, moving with tremendous speeds — up to 184,000 miles per second. They are much more penetrating than the slower-moving alpha particles and will pass through thin sheets of metal. Heavier metals like lead are more effective in stopping them than light metals such as aluminum.

Gamma rays are not particles at all, but a sort of wave motion like X-rays, though for the most part of shorter wave length and greater penetrating power. They are not completely stopped even by several inches of lead. Since they are not particles, they have no mass and carry no electrical charge.

When an atom emits an alpha particle its atomic number decreases by two units, since the alpha particle carries away two protons from the nucleus. Its mass number, however, goes down four units, since the mass number of the departing alpha particle is four (2 protons + 2 neutrons).

Emission of a beta particle, on the other hand, has no effect upon the mass number, since electrons have almost no weight. The atomic number, nevertheless, is actually increased, since the beta particle is formed by a neutron being transformed into a proton and an electron. The electron is shot out as a beta particle, while the proton remains in the nucleus, adding one to the number of protons and hence to the atomic number.

Gamma rays are generally emitted whenever a beta particle is ejected from the nucleus, and they sometimes also accompany alpha-particle emission. When someone rocks a boat on a quiet pond, waves spread out from it in all directions, and we may think of the gamma rays as the waves produced by an agitated nucleus when it has just thrown a particle overboard.

Let us consider an atom of radium as a specific example. The atomic number is 88, and the mass number 226. If we wait long enough, our atom of radium will emit an alpha particle. As just mentioned, this lowers the atomic number two units, and the mass number four units. Thus the new atom has an atomic number of 86 and a mass number of 222. It is an atom of the element radon, an entirely different substance in physical and chemical properties from radium. Its nucleus is still unstable, however, and in time another alpha particle is sent out, leaving an atom of atomic number 84 and mass number 218, an isotope of the element polonium.

But the end is not yet, for a third alpha particle is ejected, leaving an isotope of lead, atomic number 82, mass number 214. This nucleus is still unstable, but this time a beta particle is thrown out, and the atomic number rises to 83, the mass number remaining at 214. The result is an isotope of bismuth. After further successive emissions of alpha and beta particles, the atom ends up as a stable isotope of lead, atomic number 82, mass number 206.

Table I — A Radioactive Transformation Series

Particle emitted		Atomic number	Mass number	Isotope of
		88	226	Radium
alpha	← ↓			
		86	222	Radon
alpha	← ↓			
		84	218	Polonium
alpha	← ↓			
		82	214	Lead
beta	← ↓			
		83	214	Bismuth
beta	← ↓			
		84	214	Polonium
alpha	← ↓			
		82	210	Lead
beta	← ↓			
		83	210	Bismuth
beta	← ↓			
		84	210	Polonium
alpha	← ↓			
		82	206	Lead

We show in Table I the succession of transformations from radium to the end of the series, but to make the story complete we should have started with an isotope of uranium which by a similar series of particle emissions gives rise to radium itself. In addition to this so-called uranium series, two other similar series are known.

Our description of the uranium series shows that in any mass of radioactive material we actually have quite a variety of radioactive elements, some emitting alpha rays and some beta. Furthermore, any radioactive sample is not permanent, but continually diminishes in amount. Let us now answer some questions about the speed of radioactive disintegration.

Suppose we start with any weight of pure radium, say one gram. Then after about 1600 years, only half of it will remain, the other half having been converted into the lower members of the series. If now we put away the remaining half gram of radium and wait another 1600 years, half of it will disintegrate, and we will then have only one-quarter of a gram. Another 1600 years will see the remainder again cut in half, leaving us only one-eighth of a gram. After every 1600 years whatever amount of radium we had at the beginning of that period will have been cut in half, and you can see that although our sample is steadily decreasing in amount, it will take forever before absolutely all of it is gone.

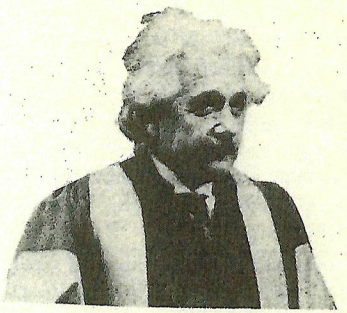
The 1600-year period in which the amount of any sample of radium decreases to one-half is called the half-life of radium. Other radioactive elements have widely different half-lives, ranging from billions of years down to a small fraction of a second. Table II gives, among other information, the half-lives of a number of typical radioactive substances, some belonging to the uranium series and some to the others.

Table II — Some Typical Radioactive Elements

Element	Atomic number	Mass number (atomic weight) of isotope	Emits	Half-life
uranium	92	238	alpha	4.45 billion years
radium	88	226	alpha	1600 years
polonium	84	210	alpha	140 days
actinium	89	227	beta	13.5 years
radon	86	222	alpha	3.8 days
proto-actinium	91	231	beta	32,000 years
polonium	84	216	alpha	0.14 second
thorium	90	232	alpha	18 billion years
thorium	90	230	alpha	83,000 years
thorium	90	231	beta	25 hours
thorium	90	234	beta	24.5 days

We have no way of predicting when any particular individual atom is going to explode, but we can make definite statements about the average behavior of the very large numbers of atoms composing the samples we study. We are in about the same position as a life insurance company with regard to the life spans of its policy holders. No one can predict how long any particular man will live, but if we have a group of 10,000 men of a certain age, we can be fairly sure how many of them will be alive a year from now. We don't know *which ones* will die, but we know *how many* will. In the same way, we do not know *which* atoms of a sample

of radium will disintegrate in the next 1600 years, but we are certain that half of them will.



Dr. Albert Einstein

We have already pointed out that the energy liberated in radioactive charges is many times greater than that involved in ordinary chemical reactions. What is the source of this tremendous energy?

As far back as 1905 Albert Einstein reached, by theoretical reasoning, the conclusion that mass and energy are equivalent. He suggested that it might be possible to find a process in which mass is converted into energy or energy into mass. His theory predicted that in such a process the amount of energy obtainable from a given amount of mass would be given by the very simple equation:

$$E=mc^2$$

in which E stands for the energy, m for the mass, and c for the speed of light.

When applied to any particular case, using the proper units, this equation gives amazing results. For example, if we could convert a dime (weighing 2.5 grams) completely into energy, the energy, according to Einstein's equation, would be sufficient to lift a weight of 15,700,000 tons to a height of one mile.

We now know that the energy observed to come from radioactive atoms is derived from the actual conversion of matter into energy. Einstein's equation shows that in order to account for the energies of the alpha, beta, and gamma rays, only a very small amount of mass need be used up, only a tiny fraction of a mass number unit, an insignificant percentage of the total.

In spite of the very great energy released, the natural radioactive elements are of no importance as general sources of energy, since those which are even relatively abundant disintegrate and release their energy with extreme slowness (remember the 1600-year half-life of radium), and no way is known of speeding up their decomposition.

In artificially produced atomic fission, on the contrary, we now have a source of even greater energy, and what is more, of energy which can be controlled. This matter is to be discussed in a later chapter.

CHAPTER IV

THE CYCLOTRON AND OTHER ATOM-SMASHING DEVICES

The high-speed alpha and beta particles shot out from the nuclei of radioactive atoms have been very valuable tools in the study of how atoms are put together. Recall from Chapter I that it was by bombarding nitrogen with alpha particles that Rutherford accomplished the first artificial transmutation of one atom into another. The discovery of the neutron and of artificial radioactivity were other consequences of the use of such particles in research.

Unfortunately, the radioactive elements, such as radium, which give us these particles are rare and expensive, and furthermore, they give us little choice as to type and energy of particle. We must take them as they come. It is small wonder, then, that physicists looked for artificial means of producing high-speed particles in larger amount and under better control.

The problem is two-fold: first, to produce the particles, and second, to speed them up so that they will have enough energy to be useful as bullets in bombarding atoms.

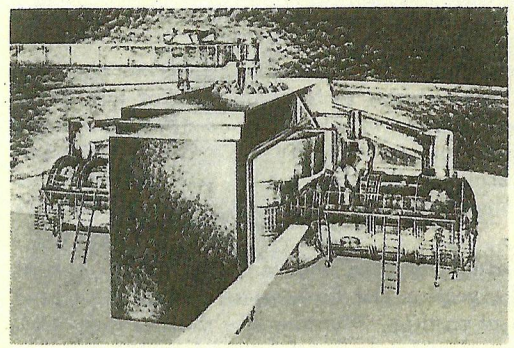
The first part of the problem is relatively easy. Recall that the atom of hydrogen consists of a nucleus, which is a single proton, around which revolves just one electron. To obtain protons, then, all we need to do is remove the electrons from hydrogen atoms, that is ionize them. The nucleus of the heavy hydrogen isotope, deuterium, contains in addition to the proton, also a neutron, and this nucleus is known as a deuteron. Thus to obtain deuterons, we simply ionize heavy hydrogen atoms. If we want alpha particles, we ionize helium atoms, since the alpha particle is a helium nucleus. The production of neutrons is another matter, which we will touch upon later.

To remove electrons from hydrogen, deuterium, or helium atoms so as to obtain their naked nuclei, we may shoot electrons at them. A heated metal filament, such as that in a radio vacuum tube, emits electrons, and if the filament is given a negative voltage with respect to its surrounding, the electrons are repelled from it with a considerable velocity.

If the space around the filament contains hydrogen at a low pressure, the speeding electrons, in colliding with hydrogen atoms, will frequently knock out of the atoms the electrons which they contain, leaving hydrogen ions, that is, protons in a free state. Under similar conditions, deuterium will yield deuterons, and helium, alpha particles. An electric arc may also be used to produce the ions.

Having formed the desired ions, we must set them in rapid motion by

giving them a large amount of energy. The most obvious method would be to place two metal plates in the apparatus and by means of a battery or generator, keep one of them charged positively and the other negatively. Then the positive ions will be repelled from the positive plate and attracted by the negative plate, and these forces will set them in motion.



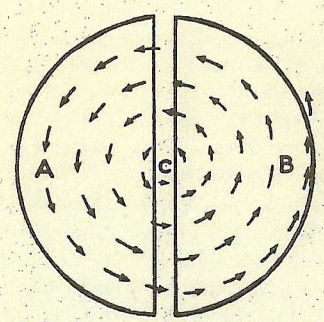
The difficulty here is that in order to give the ions high enough energies to make them useful in atom-smashing experiments, extremely high voltages are necessary, at least a million volts, and preferably much more. The production and control of such voltages are difficult, but several forms of apparatus have been built for that purpose.

The most famous of these is the Van de Graaf generator. In it, electricity is placed upon a rapidly moving paper belt by an electrical apparatus and carried by the belt to a large hollow metal ball supported on an insulator far above the floor. A potential difference of several million volts may be built up in this way between the ball and the ground. When this enormous voltage is applied to the two ends of an accelerating tube, ions produced at the positive end of the tube attain a very high speed by the time they reach the other end.

The difficulties and hazards of such extremely high voltages may be avoided if we can contrive to apply to our ions a succession of relatively small voltages. The most successful apparatus of this type is the cyclotron, developed about 1932 by Lawrence in California.

In the cyclotron the ions are made to move around a spiral path. The heart of the apparatus is a round, flat metal box, cut into two halves. These halves are called dees because of their shape like two capital letters "D" placed back to back. The dees are located flatwise between the poles of a very powerful electromagnet, weighing perhaps hundreds of tons. They are enclosed in an air-tight jacket from which the air can be removed by a vacuum pump.

In operation, positive ions are produced at the center of the dees (point C in the diagram). Dee A is made positive and dee B negative, 10,000 volts or more being used. The positive ions therefore move toward B. As they move, however, they are deflected by the magnetic field and forced into a semicircular path. Hence they quickly return to the gap between the dees. By this time, the electrical polarity of the two dees has been reversed, so that A is negative and B is positive. The ions are thus pulled across from dee B to dee A, and the pull increases their speed so that they move in a larger semi-circle than before. By the time they leave A, the polarity has again been reversed, and they are pulled back to B with another increase in speed. After an ion has been pulled back and forth from one dee to the other in this way several hundred times, its speed is as great as if it had fallen all at once through a single voltage difference of many million volts. Its path, furthermore, has gradually widened until it is at the edge of the dees, from where it may be led off for use in bombarding atoms.



The Dees of a Cyclotron

Protons, deuterons, and alpha particles may be given tremendous energies in the cyclotron. If we want neutrons, however, we must give them energy in some other way, for since the neutron carries no electrical charge, it is neither attracted nor repelled by the charged dees of the cyclotron.

Originally neutrons were obtained from atomic nuclei by bombardment with alpha particles from radioactive substances. The cyclotron now furnishes us with a convenient and powerful source of alpha particles, so in spite of our inability to speed up neutrons directly in a cyclotron, we can obtain them indirectly by allowing a beam of high-speed alpha particles (or other ions) from the cyclotron to fall upon a suitable element, generally the light metal beryllium. Neutrons in great abundance are then expelled from the beryllium nuclei.

Neutrons obtained indirectly from the cyclotron were of great importance in the studies which led up to the artificial release of atomic energy. The next chapter will explain why neutrons are of special interest as bullets for bombarding atoms.

For reasons connected with their very small weight, electrons cannot be speeded up to a useful extent in a cyclotron. The induction accelerator, or betatron, invented in 1940 by Kerst, makes up for this deficiency. By means of a rapidly changing magnetic field, it accelerates electrons to speeds greater than those of any natural beta particles. When high-speed electrons strike a solid metal target, they produce X-rays. Electrons from the betatron are capable of yielding X-rays which are "harder," that is, of shorter wave length, than those from ordinary X-ray tubes. It is likely also that these very energetic electrons will have interesting and perhaps useful effects upon atomic nuclei, but this line of research is just beginning to be opened up.

CHAPTER V

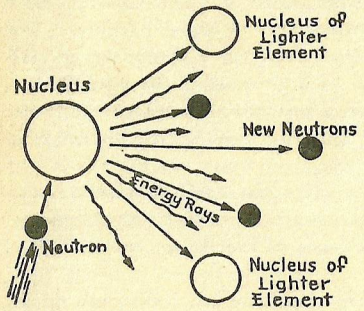
ARTIFICIAL ATOMIC ENERGY

In the chapter on atomic structure we saw that particles called neutrons are one of the building blocks from which the nuclei of atoms are constructed. They are similar in weight to protons, but carry no electrical charge. In the preceding chapter we learned that neutrons may be knocked out of the nuclei of certain light atoms such as beryllium. We come now to the part played by neutrons in the production of atomic energy.

Since neutrons have no electrical charge, they pass without hindrance among the electrons of atoms. Hence they have much greater penetrating power than the electrically charged alpha and beta particles. A neutron is stopped only when it comes so close to a nucleus that it scores a direct hit. In most cases, when a neutron collides with the nucleus of an atom, it is simply captured by the nucleus, and there is formed a nucleus which belongs to an isotope, often radioactive, of the old element.

There are a few atoms of a particular kind called fissionable isotopes, which do an especially interesting thing when hit by neutrons. These fissionable atoms are isotopes of the heavier elements, such as uranium, thorium, etc. The nuclei of these atoms are more complex in structure and contain more neutrons and protons than do atoms of the lighter elements. Thus their cohesive force is less and they are more easily split.

NEUTRON SPLITTING AN ATOM



When a neutron strikes the nucleus of a fissionable isotope, the entire nucleus splits into two pieces. The two fragments move away from each other with tremendous velocity and the energy rays which are simultaneously released appear ultimately as heat. The fragments collect an electron cloud around themselves and thus form new radioactive isotopes of other known chemical elements, such as barium. Apparently not every fission results in exactly the same fragments. It is this phenomenon of nuclear fission which constitutes the basis of atomic energy development.

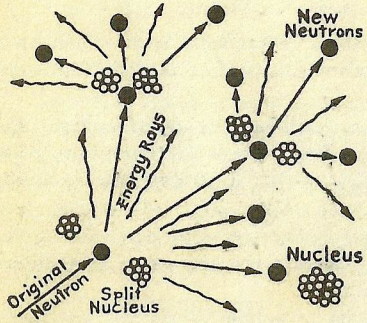
Nuclear fission, or the splitting of an atom by a neutron into two other elements, releases *artificial* or man-controlled atomic energy. The relatively slow natural disintegration of radioactive materials, such as uranium or radium, is a *natural* release of atomic energy.

If the high-speed neutron, which is sometimes referred to as an atomic bullet, can be slowed down in speed, the chances of its striking the nucleus of an atom are much greater. Several elements, among them carbon and deuterium (heavy hydrogen), have been found to exert a moderating or slowing effect on neutrons. This is the reason that graphite (carbon) is mixed with the element whose atoms are to be split.

The isotope of uranium of mass number or atomic weight 235 (U-235) is readily split by a slow-moving neutron. When this occurs additional neutrons are released, which in turn may split other atoms of uranium 235. At the same time, if atoms of uranium 238 are present with the atoms of 235 (which they always are) some of the neutrons released from the fission of the U-235 atoms are absorbed by atoms of U-238. This produces another isotope of uranium, called U-239. The U-239 atoms in turn emit a beta particle becoming neptunium, which in turn emits another beta particle becoming plutonium.

We see, therefore, that atoms of uranium 235 can be split by neutrons with the release of more neutrons, and at the same time, uranium 238 can be converted into plutonium.

CHAIN REACTION



This brings us to the so-called chain reaction. Neutrons produced by one nuclear fission fit and split other nuclei. But since atoms are mostly open spaces, a chain started in a small block of U-235 quickly dies out because most of the released neutrons escape from the block. The bigger the block, the smaller will be the percentage of escaping neutrons, and more will be left to split other nuclei. Thus, when a block of uranium 235 exceeds a certain size, the so-called critical size is passed and each 1000 nuclear fissions release sufficient neutrons to split more than 1000 additional nuclei. Under these conditions enough neutrons are produced to keep the reaction going and at the same time allow the extra neutrons to be absorbed by U-238 atoms, producing plutonium.

Plutonium is also a fissionable material and an atom of plutonium can be split by a neutron in the same way as can an atom of U-235. Thus, as the amount of plutonium formed in the reaction increases, the fission of atoms also increases and more neutrons are released.

This chain reaction is the basis of the atomic pile in which plutonium is produced and is also the basis of the atomic bomb. The difference is in the speed with which the reaction is allowed to proceed.

In Chapter III we learned that the source of the energy of radioactivity is a decrease in mass or weight of the atoms, in other words, the conversion

of matter into energy. The even greater energy released artificially in atomic fission likewise comes from the conversion of mass into energy.

When an atom of uranium is split by a neutron, two lighter atoms are formed along with several neutrons. The weights of these fragments all added together come out less than the weight of the original uranium atom plus that of the neutron which it captured. The difference is the mass which is converted into energy in accordance with Einstein's equation.

As nuclear fission is at present carried out, only about one-thousandth of the weight of a uranium atom is converted into energy when the atom is split. This is roughly one-fifth the weight of a neutron. If all, or even a large part of the mass of a sample of uranium could be changed into energy, our present atomic bombs would look pale in comparison.

CHAPTER VI

EXPERIMENTS IN RADIOACTIVITY

There are a number of very interesting experiments with radioactivity which you can perform with the materials and apparatus in your Chemcraft outfit.

The radioactive materials which are included are not harmful. The amount of radium is so small that the radioactivity is far below the point where it might be dangerous. Uranium is, of course, entirely safe to handle as its radioactivity is relatively low.

We learned in earlier chapters that radioactive materials, during the course of natural disintegration, give off three types of rays or emanations. These are known as Alpha, Beta and Gamma.

The alpha rays or particles are nuclei of helium atoms and are, therefore, particles consisting of two protons and two neutrons. Alpha particles have relatively large mass and hence do not penetrate as far as the other types of ray.

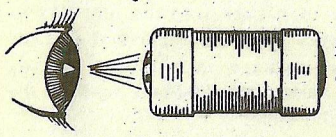
Beta rays are electrons, particles having very little weight or mass, but bearing negative charges of electricity.

Gamma rays are similar to X-rays but of shorter wave length and hence of greater penetrating power. It is the gamma rays which cause burns from exposure to intense radioactivity.

CHEMCRAFT ATOMIC ENERGY SPINTHARISCOPE

This special scientific instrument which is included in your outfit contains radium, one of the most valuable substances in the world. Radium costs about $25,000.00 per gram. When you look into your Atomic Energy Spinthariscope under proper conditions, you actually see the effect of the atomic disintegration of radium, the closest approach man has ever made to seeing an atom. This is accomplished by placing a small amount of radium compound close to a specially prepared screen. The alpha particles are expelled from the radium with a velocity of about 10,000 miles per second. As each particle strikes the screen, a flash of light is produced. These flashes, called scintillations, can easily be seen when observed through the powerful lens in the eye-piece of the Spinthariscope.

CHEMCRAFT SPINTHARISCOPE



Two rules must be carefully followed in order to successfully observe the flashes caused by the alpha particles.

(1) Your Atomic Energy Spinthariscope must be kept in a dark place for several hours before you use it. If any light is allowed to enter through the lens, the screen glows for some time. This of course makes it very difficult to see the alpha particle flashes.

(2) The instrument must be used in a dark place and you must remain in the dark for five or ten minutes before your eyes become adjusted. You will be unable to see the flashes until your eyes have become entirely adjusted to the dark. If necessary focus your Spinthariscope by moving the eye-piece in or out slightly.

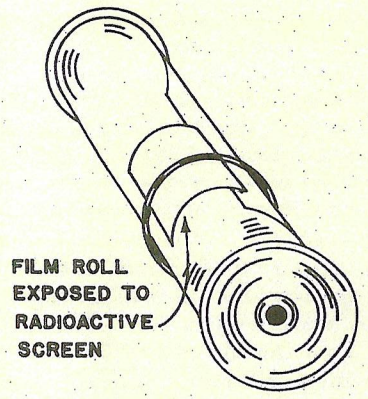
In a dark closet or at night when the lights have been turned out, hold the eye-piece of the Atomic Energy Spinthariscope to your eye and observe the continuous play of flashes on the screen. They will remind you of hundreds of bright stars twinkling in the dark sky. Most wonderful, however, will be the knowledge that you are seeing with your own eyes the effect of atomic disintegration and that the energy locked in the atoms of radium is so tremendous that this action will continue for thousands of years.

MAKING PICTURES BY ATOMIC ENERGY

The rays or emanations given off by radioactive materials affect photographic film or plates in very much the same manner as light rays. This fact opens a very interesting field for experiments from which much valuable information can be obtained.

There are several methods by which sensitive film or plates may be exposed to the emanations of radioactive substances. Great care should be taken against exposing the film or plates to light before they are developed, as the least exposure will probably spoil your experiment.

The films or plates used should be of medium sensitivity, that is, medium fast. Slow film or plates require longer exposure to the radioactive material, while fast film is difficult to handle because it is very sensitive to light.



The easiest method of making atomic energy pictures is to use an entire roll of film, removing only the metal foil wrapper, but not unrolling the film. Place your radioactive screen against the film roll and hold it in place with a small rubber band or by tying it with string. Now put the roll of film with the radioactive screen attached to it back into the film box or just wrap it up in paper and put the box or package in a drawer or any other dark place. Make note of the date and time.

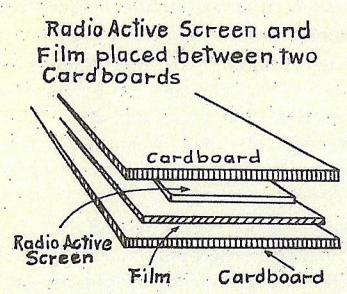
Allow the radioactive screen to remain against the film roll for at least 24 hours. Heavier markings will be obtained if a longer time is allowed.

When you remove the radioactive screen from the film roll, either develop the film yourself or have it developed by a photographer, giving instructions that the film should not be cut into sections but is to be left in one piece. When you have the developed film, unroll it and hold the strip against a light background, such as a piece of white paper. If your film has not been fogged or light-struck, you will notice a very interesting pattern consisting of a series of black images of the radioactive screen. These will be regularly spaced and will gradually become lighter toward the end of the film that was on the inside of the roll. Study the pattern and visualize the penetration of the film by the rays emanating from the radioactive screen. It is possible that some of the rays may penetrate even beyond the center of the film roll, in which case you would have a secondary pattern in between the original pattern.

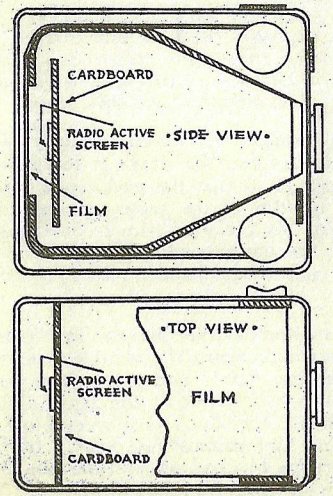
Since alpha, beta and gamma rays are all given off from uranium or its decomposition products, we might assume that each type of ray played some part in marking this film. However, alpha rays are not very penetrating, in fact they do not even pass through a heavy sheet of paper. Therefore, the markings on our film must be caused by the beta and gamma rays. Later on we will suggest experiments wherein certain other rays will be screened out so that the relative effect and, to some extent, the intensity of the different rays may be judged.

A number of methods of exposing film or plates to radioactive material will no doubt suggest themselves to the experimenter. We will set down a few ideas, however, which may be of practical value. Always be sure to place the radioactive material against the sensitive or coated side of the

film or plate. On roll film, the sensitive side is the inner side of the roll. If there is any doubts as to which is the coated side of a certain piece of film, snip off a small piece and take it into a light place. You will find the sensitive side is a dull cream color, while the non-sensitive is usually reddish and shiny. Possibly a simpler method is to place an edge of the film between your lips. The coated or sensitive side will stick to one lip, while the uncoated side will not stick to the other lip.



Film may be cut into pieces in a dark room and the radioactive material placed against the film or against any desired type of screen which, in turn, is placed against the film. The entire package is then sandwiched between two pieces of cardboard, securely fastened and wrapped in dark paper. After the exposure time is over, open the package and remove the film, being very careful to keep it away from any light until the film has been developed. The above method is, of course, the best for handling plates.



In all cameras there is a space on the inside between the lens and the film or plate. A piece of cardboard can be cut to fit across this space and the radioactive material fastened to this cardboard by means of string or a rubber band. Use thin tissue paper or cheesecloth to wrap the radioactive material in if it is desired to obtain the alpha ray markings. The camera is then loaded with the film or plate in the usual way. Turn to the first exposure position and set the camera away for the desired length of time. Do not, of course, open the shutter. Additional exposures may be made by turning the film to the next exposure position.

Many radioactive materials will mark film or plates as described above. Uranium ores, such as carnotite or pitchblende, can be used, but due to the relatively low content of uranium, considerably longer exposure time must be allowed. The ore should be wrapped in a single thickness of thin

tissue paper or cheesecloth as the alpha rays do not penetrate through glass, plastics, metals, or even a sheet of fairly heavy paper.

Thorium, which is present in gas mantles, is radioactive. Gas mantles are still used in some types of kerosene, gasoline and acetylene lamps. If you can obtain a gas mantle, burn off the protective coating, then crush the mantle and use as described above for uranium ore.

Radium is much more radioactive than uranium. In the Chemcraft outfits, a Radioactive Screen is included. This consists of a disc to which a small amount of radium-bearing material has been applied. This radium disc will mark film very much more quickly than other radioactive materials mentioned because the emission of rays is many times more rapid.

We have learned that radioactive materials, as they disintegrate, give off three kinds of rays and that these rays mark photographic film or plates. In the following experiments, we will eliminate by means of shields first one type of ray and then another type, thus showing the relative amounts of the three rays emitted by radium and its radioactive decomposition products.

The alpha rays will not penetrate any dense materials, even heavy paper. Beta rays will penetrate thin layers of most materials, except lead. Gamma rays are the most penetrating, passing through almost all materials, including lead up to a thickness of several inches.

EXPERIMENT 1—First, suppose we expose a piece of film directly to our Radioactive Screen for 48 hours. Be sure to put the radioactive screen against the sensitive side of the film. Upon developing this film, we should have an intense black spot about the size of a nickel. Save this film.

EXPERIMENT 2—Next, wrap your Radioactive Screen carefully in a piece of heavy paper or cellophane. Make sure that the screen is completely inclosed and that the ends are securely creased so that the package is tight. Now place this package against a piece of film of the same type as used before and expose it for 48 hours. When this piece of film is developed, compare the mark with that obtained from the unwrapped radioactive screen. The black spot should be about the same size as the former spot but somewhat less dark.

EXPERIMENT 3—Now wrap your Radioactive Screen in several thicknesses of lead foil and place this package against a similar piece of film for 48 hours. When this is developed, you should find only a faint spot.

In the first experiment, the film was marked by all of the rays (alpha, beta and gamma). In the second experiment, the alpha rays were blocked off hence the film was marked by the beta and gamma rays only. In the third experiment, the alpha and beta rays were blocked off and the film was marked by the gamma rays alone.

The above series of experiments can also be performed with uranium ores, such as carnotite or pitchblende. Due to the much lower rate of radioactivity of these materials, an exposure time of several weeks must be allowed, instead of a day or two as with the radioactive screen.

Various salts of uranium and thorium, such as uranium oxide, uranyl acetate, uranyl nitrate, uranyl chloride, uranyl sulfate, thorium acetate, thorium nitrate, thorium chloride, thorium oxalate, thorium oxide and thorium sulfate, as well as metallic uranium and thorium, are sometimes available in laboratories. Small amounts of these salts of radioactive metals, of course, show radioactivity and if they are available, they can be used to mark film and to demonstrate the different types of rays emitted by radioactive materials. Uranium and thorium compounds containing these metals are much less radioactive than radium and its compounds and therefore require a longer time to mark film. Experiments with any of these materials should allow about 3 to 4 times as long an exposure as would be necessary with the radioactive screen.

In concluding this chapter, we wish to point out that the preceding experiments are merely suggestive, and we believe that the ingenuity of the experimenter will lead to many additional applications of the principles described.

CHAPTER VII

SOURCES OF RAW MATERIALS FOR ATOMIC ENERGY

The fissionable atoms of uranium 235 and of plutonium (made from uranium) have been used almost exclusively so far as the source of artificial atomic energy. It is known that certain isotopes of both thorium and protoactinium also undergo fission when bombarded by neutrons. Since uranium apparently has some advantages over thorium and protoactinium as a source of atomic energy, less consideration has been given to the latter two elements. Uranium, therefore, stands first as a source of atomic energy at the present time.

Although uranium is not considered to be a very rare material, relatively few deposits of commercial importance have been discovered up to the present time. Deposits of commercial interest from which uranium has been recovered in the past occur in the Belgian Congo, Canada, Czechoslovakia, Portugal and the United States. In addition, small amounts of uranium have been produced in England, Madagascar, and Russia.

The principal ores from which uranium is recovered are pitchblende and carnotite. Pitchblende (uraninite) is a complex oxide of uranium, containing also variable amounts of lead, iron, copper, bismuth and the rare elements, radium, thorium, yttrium, helium and argon. The percentage of uranium oxides in pitchblende varies from about 64 to 89 per cent. From

a physical point of view, pitchblende is an extraordinary mineral. From it helium was first obtained. The radioactive elements, uranium, radium, polonium and actinium were first discovered in pitchblende. The discovery and purification of uranium and radium from pitchblende led to many important discoveries in chemistry and physics.

Pitchblende has been found at various localities in the United States, mostly in very small quantities. There are small occurrences in Utah, California, Wyoming, Colorado, Nevada and Texas, also in the New England states. The principal deposits of pitchblende in the United States are in North Carolina, but even these are not large producers. The Great Bear Lake deposits in Canada were discovered in 1930, and immediately attracted world-wide attention. These are believed to be the richest deposits of pitchblende so far discovered.

Carnotite consists chiefly of potassium uranium vanadate. Carnotite is a soft, powdery mineral, generally a bright yellow color, but is sometimes discolored by iron oxides or organic matter. A sample of carnotite is included in your Chemcraft outfit.

Extensive deposits of carnotite occur in the plateau regions of Colorado and Utah. These deposits occur in connection with vanadium ore.

Radium is always associated in nature with uranium in the ratio of about one gram of radium to three tons of uranium. The principal interest in uranium ores before 1941 was due to the radium content. At this time radium sold for about $25,000.00 per gram, while uranium in the form of the impure oxide sold for only one or two dollars per pound.

Thorium is reported to be more abundant in nature than uranium. This element is rather widely distributed, occurring chiefly as thorium phosphate in monazite sand. Principal deposits of this ore occur in Brazil and India.

Of all these sources of atomic energy raw materials, pitchblende is at present by far the most important.

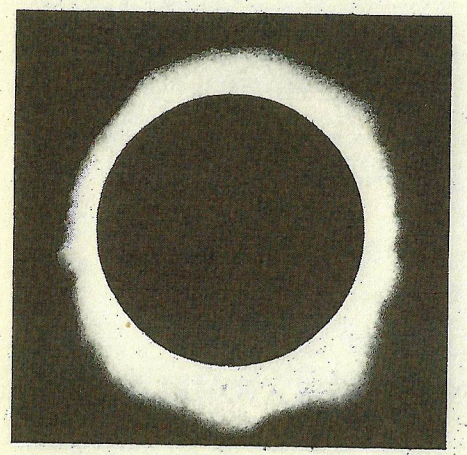
CHAPTER VIII

RADIOACTIVITY IN EVERYDAY LIFE

Certain natural phenomena heretofore clothed in the mysteries of nature have now become more clear to scientists due to our greater understanding of atomic energy. For one thing, radioactive atoms of heavy elements scattered through the depths of the earth are now believed to be playing an important part in preventing the earth from cooling off. Over millions

of years the gradual splitting of these atoms has been creating subterranean heat which has supplied the irresistible forces to push up new mountain ranges, cause volcanic eruptions, and change the shapes of continents.

It is quite probable that sometime in the distant past heavier elements existed in nature than we are able to find today. The fact that plutonium and neptunium disintegrate to form uranium, indicates strongly that these elements recently produced by man were once present in nature. In the future scientists will undoubtedly be able to explain many important facts about the formation and changes in our world, which are today clothed in secrecy.



Astronomers have applied the findings of the atom-smasher to the solution of one of the greatest problems about the sun and the stars. That is, what makes them shine and what supplies the apparently inexhaustible supply of heat. Our sun and the countless other suns throughout the universe could not produce their heat by burning in the usual sense. First, because calculations have shown that the sun would have burned away its substance long ago had its heat been produced by the usual oxidation. Second because of the temperatures on the sun, the atoms of oxygen and of oxidizable material are moving too fast to join together in the chemical union that constitutes burning. We now realize that the inexhaustible supply of heat and light emanating from our sun and other suns in the universe is the product of atomic disintegration.

We are all more or less familiar with the recent progress in the treatment of cancer with radium. It was discovered that cancerous tissue was more susceptible to the gamma rays given off by radium than was healthy tissue. Thus it has been possible in many cases to destroy or arrest the growth of cancerous tissue by radium treatment.

The extremely penetrating gamma rays from radium pass through several inches of steel. They may therefore be used for detecting flaws and cracks in heavy forgings and castings in much the same way that X-rays are used for locating breaks in bones and cavities in teeth. A small capsule of the radioactive preparation is fastened against one side of the metal object and a photographic film is placed against the other side. Since the rays pass

more readily through even tiny hidden cracks, the presence of such flaws is indicated on the film.

Another interesting application of radium with which we are more or less familar is radium luminous paint, which is used on markers and signs that must be seen in the dark, and also on the hands and dials of watches and various instruments. Radium luminous paint retains its brightness indefinitely, while other kinds of luminous paint are merely excited by exposure to light, but after a few minutes begin to lose their brilliance and gradually become dark until again excited by re-exposure to light. This property of radium luminous paint to shine continuously is based on the property of the radioactive rays to excite luminous calcium sulfide and cause it to glow in various degrees of brightness. Thus, if a small amount of radium is thoroughly mixed with luminous calcium sulfide and this mixture applied with a suitable vehicle to a surface in the form of a paint, a visible glow of light will result continuously.

Many other uses of atomic energy in our daily life will unfold in the future. Our knowledge in this field of science is in its infancy, and we may confidently expect great progress.

CHAPTER IX

THE DEVELOPMENT OF THE ATOMIC BOMB

In March 1939, only a few weeks after the discovery that uranium atoms could be split by neutrons, the possible military importance of fission was called to the attention of the government. In 1940, censorship was clamped on all atomic energy experiments, and in the summer of 1942, the entire project was consolidated under the name of "Manhattan Project." This project was probably the most important scientific and industrial achievement in the history of the world.

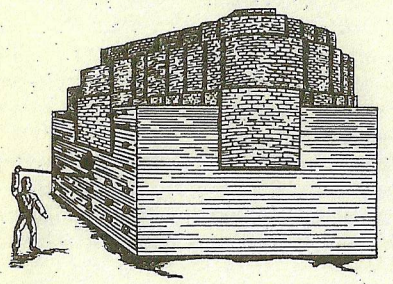
The practical application of atomic energy was at first pursued along two lines, both of which depended on uranium as the raw material.

One approach was to concentrate the fissionable U-235 isotope of uranium. This isotope occurs in all natural uranium, being .7% of the total, most of the balance being uranium 238. It had been worked out theoretically, that if a certain concentration of the U-235 isotope could be obtained in sufficient quantity to equal the critical size, spontaneous fission or an atomic explosion would result.

Two practical processes for separating U-235 from U-238 were developed and used on a large scale. One of these processes is known as the Gaseous Diffusion Process, based on the fact that a gaseous compound of U-235 will

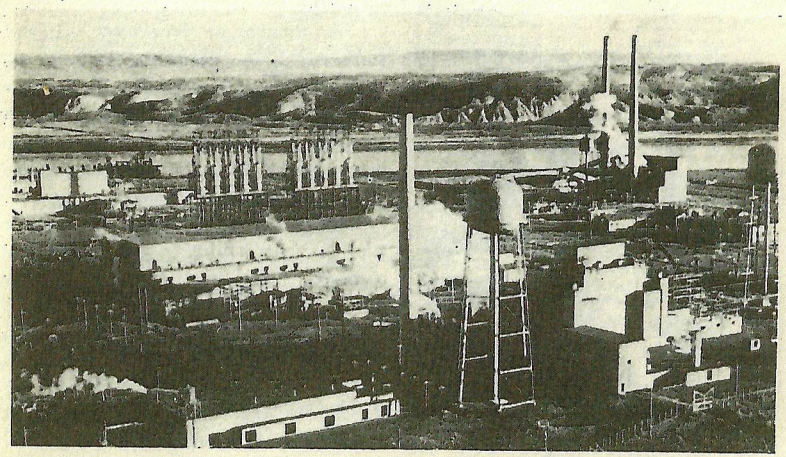
pass through a porous wall or barrier a little more readily than will the same compound of U-238. The other separation process is known as the Electro-Magnetic Process, wherein the natural mixture of U-235 and U-238 is vaporized and passed through an electric arc, where the atoms receive an electric charge, and then through an electric field where the atoms are given a high velocity. These atoms then pass into a magnetic field where the lighter atoms of U-235 curve more sharply than the heavy U-238 atoms, thus making possible the collection of the gaseous atoms in separate containers. Neither of these processes accomplished 100% separation, but these methods served to produce sufficiently high concentrations of uranium 235 for the purpose required.

THE FIRST ATOMIC PILE



The other approach to the practical production of a fissionable material was that of converting uranium 238 into plutonium, which as we have learned is fissionable like uranium 235.

In order to produce plutonium, it was necessary to construct a self-sustaining chain reaction pile. Such a pile was constructed at the University of Chicago in the fall of 1942. The pile was built on the lattice principle, that is, with lumps of metallic uranium separated by pieces of graphite.



Hanford Washington Plant

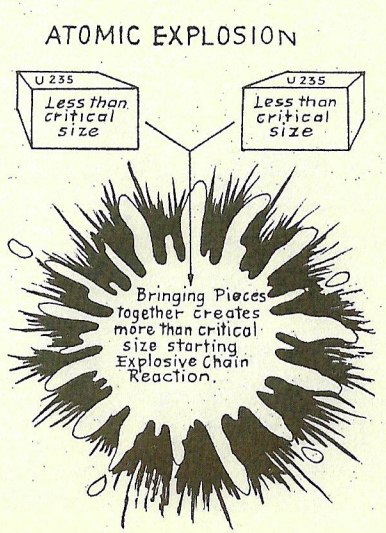
The purpose of the graphite being to slow the speed of the neutrons so that they could be more readily absorbed by the nuclei of the uranium 238 atoms.

At intervals in the pile, rods of cadmium or boron steel were inserted in slots. The purpose of these rods was to absorb neutrons should the reaction proceed too rapidly. These rods can be withdrawn or inserted as necessary.

The pile was shaped somewhat like a doorknob and was several times as high as a man. As the pile neared completion the critical size was reached, meaning that the neutrons released from atoms of U-235 in the uranium set up a chain reaction striking other atoms of U-235, releasing additional neutrons and continuing with a surplus of neutrons to convert some of the U-238 atoms into plutonium.

The successful operation of the experimental atomic energy pile resulted in the preparation of plans and the construction of larger piles for the production of plutonium in the necessary quantities. One of these piles was built at Oak Ridge, Tennessee, near Knoxville, and the others at Hanford, Washington, on the Columbia river.

With the availability of plutonium in sufficient quantities from the atomic piles and also with facilities for separating U-235 from U-238, two fissionable materials were at hand for the construction of the atomic bomb. This work was carried on in New Mexico, a short distance from Santa Fe. It is probable that bombs were made both from the concentrated U-235 and also from plutonium, the plutonium bomb being the more powerful.


ATOMIC EXPLOSION
U 235
Less than critical size
U 235
Less than critical size
Bringing Pieces together creates more than critical size starting Explosive Chain Reaction.

An amount of fissionable material (either U-235 or plutonium) above the critical size will explode almost immediately. A stray neutron could start the chain reaction and there are many sources of neutrons within these fissionable materials, in addition to the possibility of neutrons from outside sources. Accordingly, the fissionable material must be kept in separate pieces, each of which is below the critical size. The essential problem in constructing the bomb was to arrange the separate pieces of fissionable material so that they could be brought together instantaneously at the time the bomb was to explode.

The explosion of the atomic bomb is therefore a chain reaction wherein a neutron strikes the nucleus of a fissionable atom, splitting it apart and in turn, releasing other neutrons to strike other atoms, and so forth. When the critical size referred to above is obtained, this chain reaction spreads so rapidly as to be instantaneous. The release in one fraction of a second of the atomic energy produced by the fission of the mass of material is beyond the force of any explosion heretofore created by man.

An atomic bomb produces great material damage by the terrific blast wave set up in the atmosphere. It is the shock of air pressure which breaks in walls and roofs of buildings and causes most of the damage to property. Intense heat and light are also produced from the explosion. This, of course, is the cause of uncontrolled fires which follow an atomic bomb blast.

The atomic bomb, completely unlike other explosives, emits an enormous number of gamma rays at the moment it explodes. When an atom undergoes fission, not only are fragments and neutrons released, but in addition, much high-energy radiation. Therefore, at the time the bomb explodes, people in its vicinity are exposed to what amounts to a severe over-dose of X-rays, which cause disintegration of the tissues. The fragments split from atoms of the bomb which are left over after the bomb has exploded are radioactive. They continue to emit radioactive rays for several months. This means that the vicinity of the explosion of an atomic bomb is unsafe for human habitation for some time after a bomb has exploded.

CHAPTER X

THE PRINCIPLE OF THE HYDROGEN BOMB

At this point it might be well for the reader to refresh his memory on the structure of the atom as described in Chapter II, especially the portion pertaining to isotopes. We know quite accurately the proportionate weights of practically all the known atoms and their isotopes. All of these weights are very close to whole numbers, as would be expected from the fact that all atoms are composed of protons and neutrons weighing almost exactly one unit apiece, and of electrons weighing almost nothing. But although the atomic weights are close to whole numbers, they are not exactly whole numbers, and the differences are important.

If we take the difference between the atomic weight of an isotope and the nearest whole number and divide this difference by the whole number, we obtain the so-called "packing-fraction" of the isotope. The packing-fraction is related to the mass which is converted into energy when the nucleus is built up out of its constituent particles.

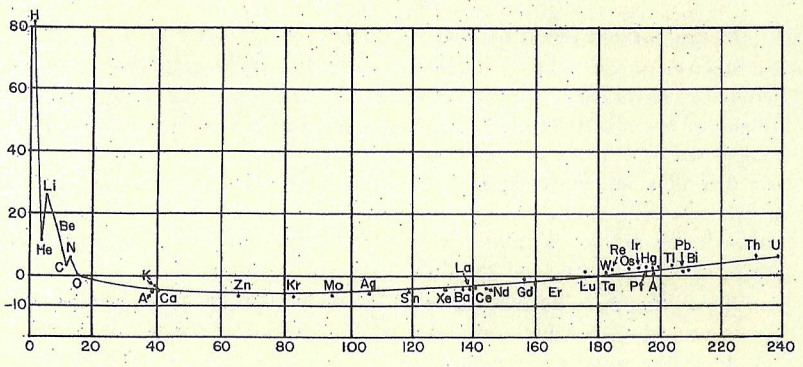
Let us arrange the elements in order of atomic weight and plot vertically on a graph the packing-fraction of each. The result is the packing-fraction curve shown in the drawing. The very light nuclei have large packing-fractions, and the very heavy nuclei also show an increase in packing-fractions as compared with those in the middle. The line of zero packing-fraction passes through oxygen simply because oxygen is the standard of the system of atomic weights.

The packing-fraction curve shows that if an atom of uranium splits apart to form two atoms near the middle of the curve, energy is released. This is the source of the energy of the atomic bomb. If, however, we could cause several atoms of hydrogen to combine so as to form an atom with a lower packing-fraction, still greater energy (per unit weight) would be available. This is the source of the energy of the sun and stars, and it is this energy which it is proposed to tap in the hydrogen bomb.

Two forces are at work inside of an atom. First, an electrical repulsion which makes the positively charged protons repel each other as similar electric charges usually do. Second, the so-called binding force which causes protons and neutrons to attract each other at very short distances equivalent, say, to the diameter of an atomic nucleus. At greater distances, the electrical repulsion force becomes the main force at work and the binding force falls off rapidly as the distance between a proton and neutron increases.

Suppose you could take a small assortment of neutrons and protons and squeeze them closely enough together for the binding force to act. They would snap into an atom, releasing energy as they did so.

PACKING–FRACTION CURVE



To make a very large atom, you would have to shove the protons and neutrons in forcibly because the diameter of the big atom is getting close to the limit of attraction of the binding force and the electrical repulsion between protons is almost as strong as the binding attraction. Such an atom would of course be very unstable, which is one of the reasons that the very heavy atoms are the ones which exhibit natural radioactivity.

Certain of the heaviest atoms, such as plutonium and the uranium isotope of mass 235, may be caused to split apart by neutrons striking their nuclei. Two middle-weight nuclei are produced and several new neutrons are released. The energy liberated depends upon the difference in the packing-fractions of the original atom and of the new ones. Under suitable conditions the neutrons released by splitting atoms of uranium or plutonium produce still more neutrons and set up in this way a self-sustaining chain reaction.

Now let us go to the other end of the packing-fraction curve where, as we have learned, we obtain energy by putting light atoms together instead of disintegrating heavy atoms. It is quite evident that the amount of energy contained by combining a gram of hydrogen atoms is vastly in excess of the energy obtained by disintegrating a gram of uranium-235 atoms.

It may sound very simple to compress hydrogen atoms and neutrons so that they would snap together forming helium and release enormous amounts of atomic energy. The difficulties, however, are tremendous. Ordinary hydrogen fuses into helium only in a complicated series of steps much too slow to be of interest on the earth, though it is in progress on a gigantic scale in the sun.

It is believed, nevertheless, that either, or both, of the two rarer isotopes of hydrogen, deuterium and tritium, could be made to form helium by subjecting them to the extremely high temperature reached in the explosion of an ordinary atomic bomb. The deuterium nucleus contains a proton and one neutron, and that of tritium a proton and two neutrons. Although these two isotopes have all the chemical properties of hydrogen, their nuclear properties are entirely different.

Deuterium is readily available since 1 part in 5000 of natural hydrogen is deuterium and it can be separated by electrolysis of water. Tritium, however, would have to be manufactured in uranium piles from an isotope of lithium, Li6. The lithium isotope, Li6, when bombarded with neutrons, would form helium and tritium.

The temperature in an atomic bomb explosion is measured in millions of degrees and is probably high enough to touch off the fusion reaction of deuterium and tritium. Of course in a very small fraction of a second, the bomb begins to expand and to cool. A major problem is, therefore, how to keep the deuterium and tritium atoms from being scattered by the explosion before they have a chance to participate in it. In order to cram enough of these atoms into a small space they would have to be liquefied

by cooling nearly to the absolute zero, and they would have to be kept cold until the bomb was exploded.

The power of the hydrogen bomb is apparently limited only by the quantity of hydrogen isotopes which can be made available within the bomb under conditions suitable to their fusion into helium.

CHAPTER XI

THE FUTURE OF ATOMIC ENERGY

The entire field of atomic energy is in its exciting infancy. The tremedous power locked in the atom was, out of war-time necessity, first released for purposes of destruction. But today the great scientists in the leading laboratories of the world are bending every effort to adapt this great force to constructive peacetime uses.

Because these more laudable efforts on the part of scientists to harness this great power are in the early stages of development, it is impossible to foresee the results that will be arrived at in the future. We do know, however, that the constructive forces of atomic energy are being applied experimentally in the following fields of science.

POWER PRODUCTION

Many suggestions have been offered for the use of atomic power. Among these are power and heat supply for cities and large industrial plants, power plants for ships, and power plants in remote places to operate mines or to recover other natural resources. From the point of view of the public welfare, the introduction of such a new source of power is a clear gain. If it could lessen the cost of heat and power to our cities, it would be a stimulus to every industry. If it could give cheaper power where industry and agriculture need it but cannot now get it, it would extend our economic frontiers. These are possibilities that future research and development may make realities.

TAGGED ATOMS

The hundreds of radioactive isotopes now available as by-products from atomic energy piles will prove to be very important in our future lives. Chemically indistinguishable from the ordinary form of the element, these isotopes serve as tagged atoms when mixed with stable atoms of the same element. The atoms of the radioactive isotopes mix and move with the stable atoms, and they serve to identify and mark atoms of this particular element wherever they may travel. Identification of the tagged atoms is possible because they are radioactive and emit alpha, beta and gamma rays, which may be detected by a sensitive screen, a film or by a Geiger counter.

BIOLOGY AND MEDICINE

Present developments indicate that the greatest promise of atomic energy in biology and medicine is in the use of radioactive tracers or tagged atoms and of intense radiations. For the first time, the opportunity is now at hand to attack thoroughly an almost infinite number of problems which are of concern to the fundamental mechanisms of life processes. This is accomplished by the introduction of radioactive isotopes of various elements into the various functioning parts of animal and plant organisms, and by this means, to follow and analyze the functioning of their organs.

The application of radiation therapy should be widened by the great variety of radioactive products made available by the development of atomic energy. While there is no evidence at the time that the rays from these artificial radioactive materials will supersede X-rays, at the same time, we may expect great progress in this general field.

ENGINEERING

In the design and testing of machinery and in many other phases of engineering, radioactive tracers or tagged atoms and other radioactive products have promising applications. Radioactive tracers could be applied to problems of wear and lubrication of moving parts. They could be used for tracing flows of liquid or gaseous materials. They might be employed for reducing static electricity, particularly in explosives plants and in the printing industry. Radioactive sources of gamma rays could be used as substitutes for industrial X-ray machinery. Such a source of rays being small in size could be used in places where an X-ray machine would not be practical.

METALLURGY

In metallurgy the use of tagged atoms again offers many possible applications. The diffusion of an element into itself or into alloys of which it is a component could be followed if the diffusing atoms were radioactive. Identification of traces of impurities, which often affect the properties of metals and alloys, could be made by adding a radioactive form of the suspected impurity and photographing the resulting mixture by microradiographic methods.

CHEMISTRY AND CHEMICAL ENGINEERING

Radioactive materials, it is believed, will come to play an important part in industrial chemistry. Now that these materials are less expensive and in much wider variety of chemical forms, more uses will be found for them. The availability of a variety of radioactive tracer elements will offer possibilities for solving questions heretofore difficult to answer, since radioactive atoms of a given element will travel with their non-radioactive brothers, giving a positive means of identifying this element in molecular and in colloidal forms. The radiations from atom-splitting chain reactions are capable of inducing chemical reactions which otherwise could not be carried to completion.

PHYSICS

The new possibilities for producing high-energy gamma rays as well as fast and slow neutron beams, and alpha and beta rays in intensities vastly greater than ever before, will aid in the solution of the basic unsolved problems of modern science; the structure of matter and the nature of radiation. It may also be possible to study the properties of matter under immensely high temperature conditions, somewhat resembling those in the stars.

THE GREAT UNKNOWN

Fifty years ago it was evident that X-rays were useful for seeing through objects, such as the human body, which are opaque to ordinary light. It could not be predicted that X-rays would become a powerful weapon in the fight against cancer, or that the study of X-rays would lead to the discovery of radioactivity and stimulate the development of radio, radar, and a host of electronic devices. Such unforseen developments are the result of every great discovery. It would, therefore, be surprising if the most important consequences of the release of atomic energy are not in directions as yet unpredictable.

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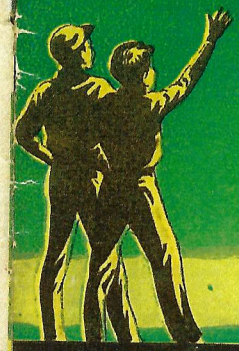
$_{93}Np^{239}$

$E = mc^2$

$_{88}^{226}$

$_{94}Pu^{239}$

GAMMA



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